Abstract

In the upcoming years, the energy requirements for buildings will have an ascending tendency regarding low energy consumption, primary reduction in greenhouse gases (CO2), increase of renewable energy sources and overall reduction of peak loads. Main goal of project SWIVT (www.swivt.tu-darmstadt.de) is to enhance, rebuild and optimize energy consumption in an existing settlement located in the city of Darmstadt by connecting several separate buildings into one energetic unity. In that sense, a new building block will be introduced into existing quarter state as an entity which can in time intelligently share its energy surplus with other buildings by means of integrated energy storage system. So that the energy balance in every time step between buildings and network will be improved. To ensure this kind of system with smart energy optimization, there is a need to connect every component of the system and think of a plausible solution of running the system

Keywords - Storage system, optimization, energy surplus, microgrid
1. Introduction

Optimization process for the operating system is conducted by means of linear and mixed integer linear programming. The goal of the optimization method is to ensure the production and cover the heat consumption of the consumers on the one, and to gain a profit on the other hand. Goal function is thus guided by minimizing the money losses and ensuring that, for each time step, the gas and electricity prices from TSO are taken into account.

Simulation had been conducted in the project for 4 scenarios depending on the various heat sources, heat and power storage technologies and state of the buildings. In order to work, every optimization method must have its own goal function which in our case is profit based. For covering the heat load in the microgrid, a CHP system or heat pump is used in a combination with auxiliary heater and heat storage. So, in the case when there is no heat storage, CHP unit is necessarily working in the regime of covering the current heat demand, without the ability of adapting its heat production to the gas and electricity prices. System connectivity, installed units and operation management are dependent on each other, thus a proper preparation before running the simulation is needed:

- Heat losses calculation and measurement of the existing settlement state:
  - In-situ measurements of electricity and heat consumption
  - Research of the site and implementing the obtained data into simulation software for further calculation
- Modelling the whole district in IDA-ICE software for obtaining the actual heat consumption curves, this had to be done for 4 main strategies which include different operation components and for existing state of the buildings,
- Simultaneously developing strategies with the results of software calculations and maintaining a constant connection with the project partners who are in charge of implementation and development part,
- Calculating the heat consumption curves from German Norm VDI 4655 for comparison to results from software package and for obtaining the reference values for validation of the simulation,
- Developing a code for optimization and finally the simulation with MATLAB® software
Determination of the capacity and the size of the heat and electricity storage units which are going to be implemented into the small demonstrator unit and subsequently into the real district in Darmstadt, Germany.

In the scope of the project a lot of research work is being done on the institute for construction materials in Stuttgart. Therefore, for developing a heat storage concept based on phase change material, the capacity and size of our storage tank has to be determined by calculation and simulation in Matlab®.

Four core strategies were made before managing the optimization part of the project. Differences between these four strategies are in the state of building renovation and thermo-electrical components.

Fig 1. System schematics
2. Input data and Preparation

Goal of preliminary design power was to illustrate thermal and electrical loads in a MATLAB environment using known literature and MATLAB predefined functions.

Thermal loads are computed from two sources: first one is from a simulation with IDA-ICE software (Fig. 3.) with the boundary conditions of existing settlement, second one is calculated from a known German norm VDI 4655 (Fig. 2.). Reason for calculating thermal loads from VDI 4655 is that every project participant could have the same data for calculating residual loads which are needed as input data to thermal and electrical energy storage calculations.

Results from IDA-ICE are closely similar to those ones from the norm, so based on this correlation we can conclude that both calculations were correct. VDI 4655 provides a recipe for calculation of heat, electricity, and warm water consumption based on single or multifamily houses. We used calculation for reference load profiles of multi-family houses for use of CHP systems. For adjustment of reference profiles, an hourly distribution of temperature and cloud cover was used. For obtaining overall heat and electricity consumption in a microgrid, calculated curves are multiplied with the number of residential spaces with specific characteristic heat energy consumption.

![LDC curve heat demand](image)

Fig 2. Load demand curve for settlement which consists of 6 buildings (VDI 4655)
Input data for IDA-ICE software was generated using in-situ measurements and technical data from building design plans. Input data for electricity consumption was also obtained from two sources: IDA-ICE and in-situ measurements from three different power stations shown on Fig 4, on the left and right side, respectively.
Fig. 5 shows the global irradiation data in the area of Darmstadt in the 2014, which also served as input data in modeling process. In the preliminary negotiations was decided that 25 % of the total roof are will be covered by solar thermal panels and 75 % by PV modules.

Matlab® model is designed in that way that is independent of the input data, so all of this data could be changed in any moment. Reason for this was that we have four defined strategies in the project and writing the code for all strategies would be unnecessary. This way code is applicable for any system optimization strategy.
Components:

a) CHP unit (Combined Heat and Power unit)
b) Auxiliary heater
c) PV panels
d) Solar thermal panels (one case)
e) Thermal storage unit (TES)
f) Electrical storage unit (EES)
g) Electric grid

Input data:

- **CHP unit:**
  
<table>
<thead>
<tr>
<th>Maximum heat power</th>
<th>220 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum elec. power</td>
<td>180 kW</td>
</tr>
<tr>
<td>Minimum heat power</td>
<td>40 kW</td>
</tr>
<tr>
<td>Minimum elec. power</td>
<td>35 kW</td>
</tr>
<tr>
<td>Heat efficiency</td>
<td>55,2 %</td>
</tr>
<tr>
<td>Power efficiency</td>
<td>35,9 %</td>
</tr>
<tr>
<td>Overall efficiency</td>
<td>91,1 %</td>
</tr>
</tbody>
</table>

- **Auxiliary heater:**
  o maximum output power: 230 kW,
  o maximum heat power of auxiliary heater is somewhat higher than the difference of maximum thermal load which is present in one year and maximum heat output power of the CHP units,
  o Efficiency of aux. heater: $\eta_{aux} = 0.7$.

- **PV and solar thermal panels:**
  o Total roof area distribution (1000 m²):
    - Solar thermal: 25 %,
    - PV panels: 75%.
  Technology of Polycrystalline silicon with vacuum technology → constant efficiency ($\eta_{pv} \approx$ const.)
3. Simulation and Results

5.1. Basic strategy

First, the simulation was conducted with a basic strategy of system operation management so the storage capacity could be closely determined. That is why the storage capacity was set to be unlimited and the system would start with already filled storage tank, so the maximum storage capacity of one storage system is set to 0. Results are shown on the fig. 7a, 7b and 7c.

Based on the results from basic strategy the threshold for storage capacity was set to 1500 kWh. It was assumed that the CHP system, when it starts working, it works for at least three hours because of the efficiency reasons. When there is no stored heat in the tank, CHP and auxiliary heater are covering the base and peak loads, respectively.

Fig 6. a) Simulation with basic strategy for first 1000 hours in a year; b) TES with a limited capacity; c) TES with an unlimited capacity
Basically, next step was to implement some new structure variables which can be incorporated as base to profit based function. So logically, first there were the electricity price which value is determined by transmission system operator and are easy to predict, then there were gas prices which are being, due to the stochastic nature of gas market, held constant. Electricity prices are shown on the Fig 6.

These figures are production values, i.e. with that price the power plant is selling the produced electricity to the grid distributor which then distributes it to the consumers. The values of electricity prices were taken from the Nordpool Elspot prices site for 2014.

Goal function:

\[
\min \{loss(t)\} = \text{price}_{\text{gas}}(t) \times (G_{\text{CHP}}(t) + G_{\text{AH}}(t) - S(t + 1)) \pm \text{price}_{\text{elec}} \times E_e
\]
5.2. Strategy with Linear optimization

System operation for one winter week with Strategy I is shown on the Fig. 7, 8 and 9. Figure 7 and 8 are showing a system with no solar thermal panels for one winter and one summer week (input data: IDA-ICE). For every week (case) there are three figures showing the system operation for heat consumption, electricity consumption and the residuals were being written down on the fig.*c) for every case.

![Fig 8. Simulation results of one winter week in 2014 (mixed integer linear programming): a) Heat consumption; b) Electricity consumption, c) Heat storage state and the electricity export/storage](image-url)
Fig 9. Simulation results with Solar thermal panels (winter week): a) Heat consumption; b) Electricity consumption, c) Heat storage state and the electricity export/storage

System operation of running a microgrid with solar thermal panels plays an important role in the scope of this project mainly because of the heat storage size and capacity. In this case the auxiliary heater was excluded.

Fig 10. System operation for one summer week: a) Heat consumption; b) Electricity consumption, c) Heat storage state and the electricity export/storage
5.2. *Strategy with 12 Hour predictive controller*

In order to fully describe the disadvantages of previous strategies, this method had been developed. It calculates the solution of goal function in every hour with the structural variables which are also calculated in every hour and dependent on the values of electricity prices, global sun irradiation and the energy consumption in the next 12 hours.

As can be seen from Fig. 10, heat storage tank is charging and discharging accordingly to current state of the system. Moreover, in some periods the auxiliary heater is switching on, regardless of the gas price and fills the storage tank for a further use in periods of unfavorable electricity market conditions.
In the transitional week results some of the advantages can already be seen, especially regarding heat storage state. It can be seen that the storage is never completely filled, that is because the model is adopting its behavior based on the values on the electricity market, energy consumption and environmental conditions (PV) for the next 12 hours.

The advantages of third operation management strategy can be clearly seen in the summer week operation in comparison to the first strategy. Here the storage tank is never completely filled, so in the sense of profit enhancement, this case represents the most efficient one. It’s also represented by small amount of electricity export due to small number of operating hours of CHP unit.
4. Summary

It is obvious that a smartgrid system can’t work without a proper system management operation system, thus before installing and dimensioning every system there has to be a strategy of system operation. That kind of strategy requires a good connectivity and flexibility of the system components, especially if the system has a large number of units which are producing heat and electricity from the renewable sources. As it can be seen, of all three proposed strategies, third one is the most profitable one and integrated in our system it can make large savings considering heat storage state.

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References